2.6 Designing a Helmet

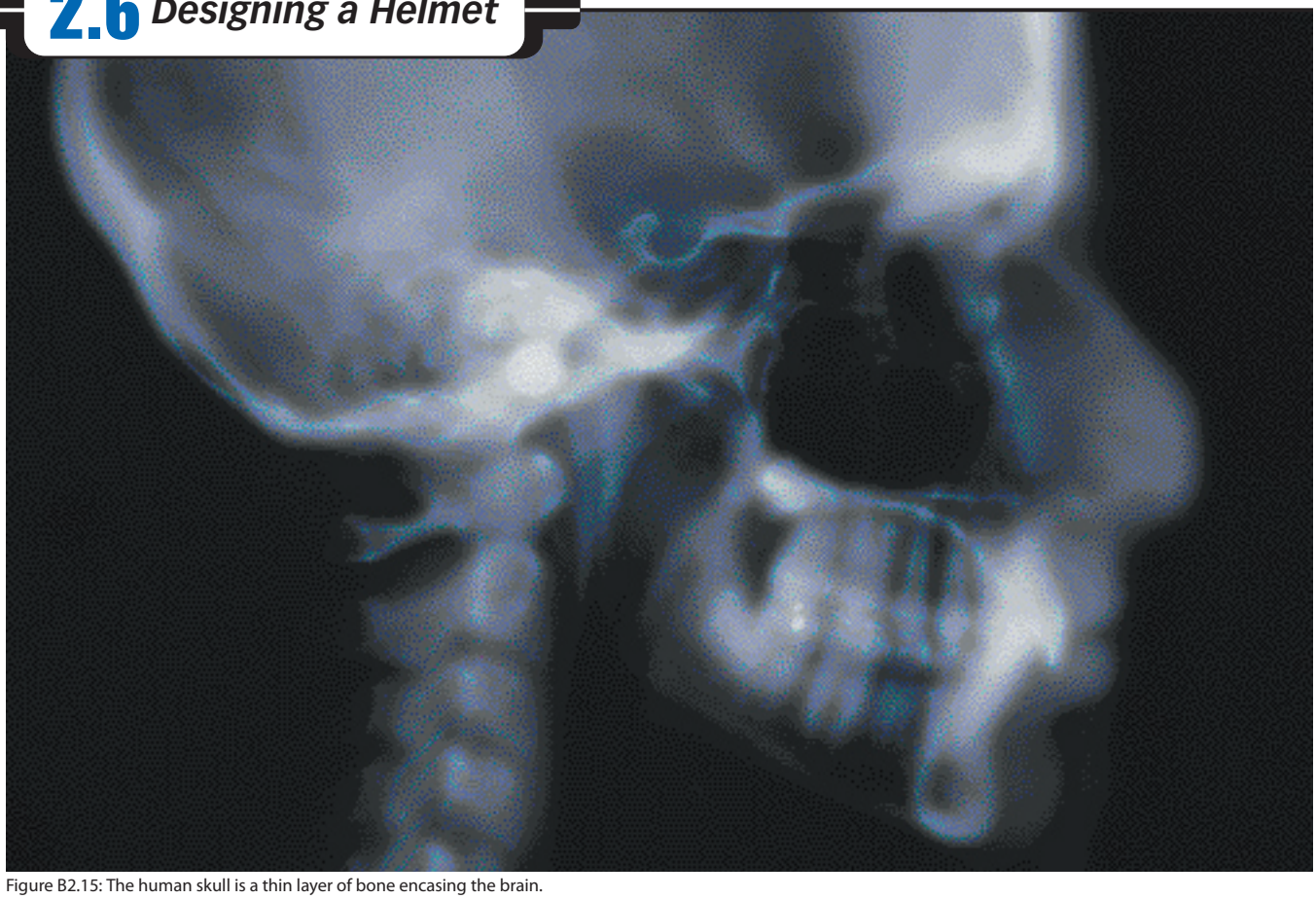


Figure B2.15: The human skull is a thin layer of bone encasing the brain.

If you happen to drop an expensive MP3 player onto a cement sidewalk, you might be disappointed if it no longer works; but at least you can have it repaired or replaced. There are many more on store shelves and the newer models often come with improved features. If you have the misfortune of having your head hit a cement sidewalk, the long-term consequences could be much more serious. Although medical science has learned a lot about the workings of the brain, only so much damage can be repaired; and, unlike your MP3 player, an off-the-shelf replacement is out of the question.

Figure B2.16: Here are a few examples of how people protect their heads at work and at play.

People who are exposed to hazards that could lead to head injuries and possible brain damage take protective measures while at work or at play. In short, they wear helmets.

Design Considerations

The kinds of hazards that the user is expected to encounter play a significant role in the design of helmets. At first glance, a helmet used for skateboarding might seem to be protecting a user from hazards similar to those faced by a cyclist. However, a well-designed skateboard helmet also has to protect against blows to the back of the head, because skateboarders are much more likely to fall backwards.

You will have an opportunity to design and test a helmet that must protect the very fragile skull of an egg test dummy. As you can see, some of the features of the egg test dummy are imaginary: a drawn-on face complete with ears and hair. However, the essential characteristics model a head quite nicely: a rigid but crackable shell enclosing a central yolk surrounded by fluid. You will have to apply everything you have learned in this unit by designing a helmet to protect the egg test dummy from a serious collision. Just as the designers of bicycle helmets have to balance the need for maximum protection with comfort and practicality, your design must address these three key characteristics:

1) The egg test dummy must be protected from a frontal collision against a rigid barrier.
2) The egg test dummy must have no covering over its eyes and ears.
3) The egg test dummy's helmet must continue to provide protection after a number of severe frontal impacts.

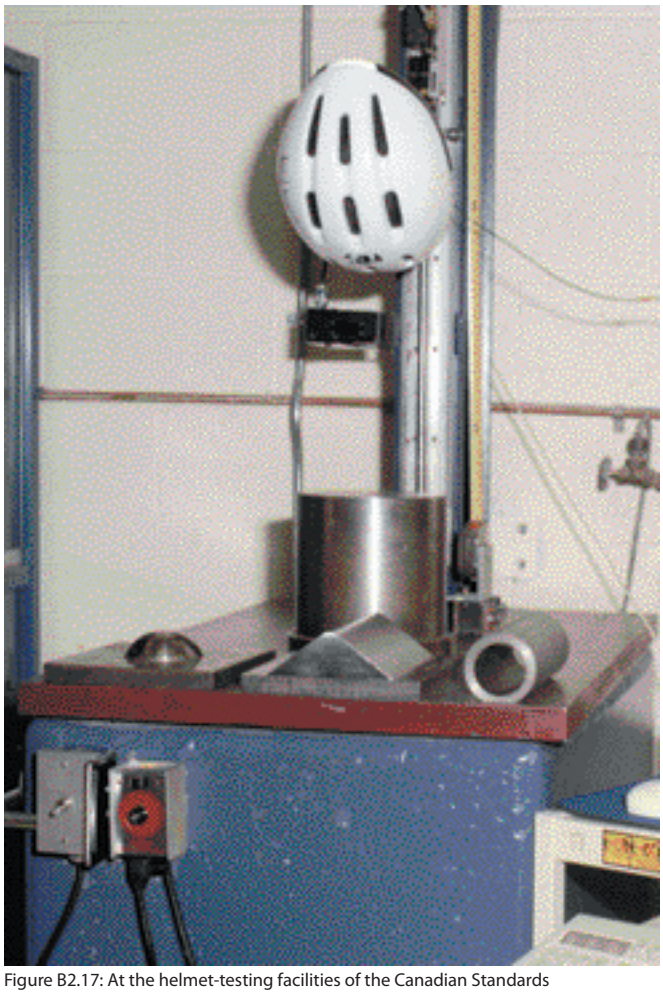


Figure B2.17: At the helmet-testing facilities of the Canadian Standards Association, helmets are loaded with a headform and then dropped onto a heavy metal anvil.

Practice

21. Identify the parts of the egg test dummy that correspond to the skull and brain of a human head.
22. Consider the list of the three design characteristics for the egg test dummy's helmet. Identify the design characteristic(s) that make the egg test dummy's helmet similar to a bicycle helmet as well as those that make it different from a bicycle helmet.

Testing Procedures

For a helmet to be certified by the Canadian Standards Association (CSA), it must pass a number of very specific tests. The CSA tests for bicycle helmets include a drop onto a flat anvil, a drop onto a cylindrical anvil, a test to ensure the helmet stays in the correct position on the head, and a chin-strap test. The data collected from these tests includes measurements of energy, mass, time, velocity, acceleration, and force. The helmets that pass being dropped onto the anvil are designed to provide protection during large changes in momentum when an equally large impulse is delivered to the helmet.

The helmet you design will need to survive a collision with a concrete block. In order to carefully control the variables in the testing procedure, a swing will be used. The apparatus is shown in Figure B2.18.

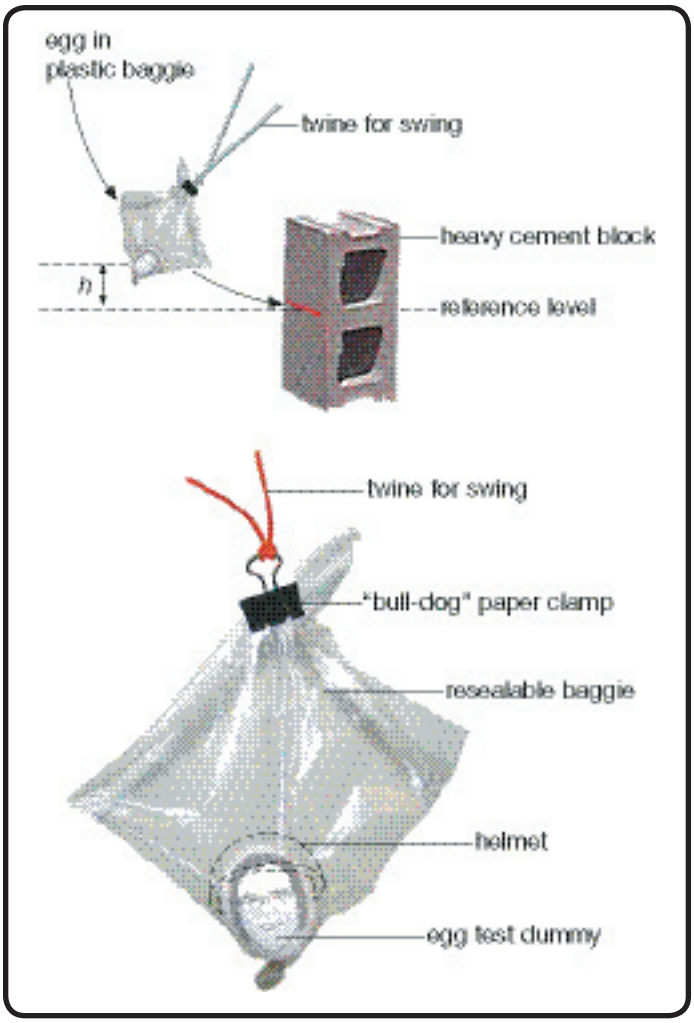


Figure B2.18: This swing apparatus will need to be set up for the investigation that comes later in this lesson.

To ensure that the helmeted egg test dummy has a frontal collision, a swing is used instead of a vertical drop. The twine that forms the swing prevents twisting and turning as the egg test dummy accelerates toward the cement block.

The swing also provides a convenient way to determine the velocity of the egg test dummy at the moment of impact. Recall from previous science courses that whenever an object is forced to move in the same direction as an applied force, **work** is done on that object. So, when the egg test dummy is pulled back from its rest position near the cement block, work is done on the egg. Even though the path it moves through is a curve, the only force that has to be overcome is the force of gravity; only the vertical distance (the height above the reference level) matters. Once the egg test dummy is pulled back and held in some new position, the work done to change the position of the egg is equal to the **gravitational potential energy** of the egg.

The following equations summarize this review of gravitational potential energy and work:

$$E_{p(grav)} = W$$

$$E_{p(grav)} = F \cdot \Delta d$$

$$E_{p(grav)} = mg \cdot h$$

gravitational potential energy of egg and other contents in baggie

height above reference level

$g = 9.81 \text{ m/s}^2$

mass of egg and other contents in baggie

- energy: the ability to do work
- law of conservation of energy: a law stating that when energy changes from one form to another, the total energy of the system remains constant
- kinetic energy: energy due to the motion of an object

If it can be assumed that very little **energy** is lost to overcome air resistance and other frictional effects as the egg test dummy swings toward the block, then according to the **law of conservation of energy**, the gravitational potential energy of the egg should be converted into energy of motion. This energy of motion is called **kinetic energy**. Recall from previous courses that the kinetic energy of an object depends on its mass and speed. The following equations summarize the relationship among speed, mass, and kinetic energy:

mass of egg and contents in baggie

kinetic energy of egg and contents in baggie

$$E_k = \frac{1}{2}mv^2$$

(speed of egg)^2

$$v = \sqrt{\frac{2E_k}{m}}$$

Example Problem 2.13 indicates that if you apply these ideas about work and energy from previous courses to the motion of the egg on the swing, it is possible to determine the speed of the egg the instant it collides with the block. Even though there is a small amount of bouncing, you can assume that most of the momentum was transferred in the impact and that the egg stops. This assumption combined with the idea that all of the potential energy converts into kinetic energy allows for reasonable approximations of impulse, acceleration, and force.

- work: the transfer of energy from one object or system to another when a force is applied over a distance
- gravitational potential energy: energy due to the position of an object above Earth's surface

Example Problem 2.13

An egg test dummy is fitted with a helmet and sealed in a plastic bag. The mass of the egg, helmet, baggie, and paper clamp is 0.085 kg. The egg and its accessories are attached to the swing and pulled back so that they are now 0.40 m above the reference level. The egg is released and swings down to collide with the cement block.

a. Calculate the gravitational potential energy of the egg and its accessories when it is 0.40 m above the reference level.

b. Determine the kinetic energy of the egg and its accessories when it collides with the cement block. Explain how this energy is transformed in the collision.

c. Calculate the speed of the egg and its accessories the moment just before impact.

d. Calculate the magnitude and direction of the momentum of the egg and its accessories just before impact.

e. Even though there is a small amount of bouncing, assume the egg and its accessories stop immediately after impact. Use this information to approximate the change in momentum of the bag and its contents.

f. Calculate the impulse required to stop the bag during impact.

g. If the impact lasts for 0.040 s, determine the force that acted upon the bag and its contents during the collision using the equation for impulse.

h. Determine the acceleration of the egg and its accessories over the 0.040 s.

i. Use Newton's second law to confirm your answer to question g. by calculating the force that acted on the bag and its contents.

Solution

a. $m = 0.085\ \text{kg}$

$h = 0.40\ \text{m}$

$g = 9.81\ \text{m/s}^2$

$E_{p(grav)} = ?$

$$\begin{aligned} E_{p(grav)} &= mgh \\ &= (0.085\ \text{kg})(9.81\ \text{m/s}^2)(0.40\ \text{m}) \\ &= 0.333\ 54\ \text{J} \\ &= 0.33\ \text{J} \end{aligned}$$

The gravitational potential energy of the egg is 0.33 J.

b. $E_{p(top)} = 0.333\ 54\ \text{J}$

$E_{k(bottom)} = ?$

$$\begin{aligned} E_{k(bottom)} &= E_{p(top)} \\ &= 0.333\ 54\ \text{J} \\ &= 0.33\ \text{J} \end{aligned}$$

The kinetic energy of the egg when it strikes the cement block is 0.33 J. During the collision, this energy is transformed into work, which changes the shape of the helmet and possibly the egg.

c. $E_k = 0.333\ 54\ \text{J}$

$m = 0.085\ \text{kg}$

$v = ?$

$$\begin{aligned} E_k &= \frac{1}{2}mv^2 \\ v &= \sqrt{\frac{2E_k}{m}} \\ &= \sqrt{\frac{2(0.333\ 54\ \text{J})}{0.085\ \text{kg}}} \\ &= 2.801\ 428\ 207\ \text{m/s} \\ &= 2.8\ \text{m/s} \end{aligned}$$

Note: $\sqrt{\frac{2(0.333\ 54\ \text{J})}{0.085\ \text{kg}}} = \sqrt{\frac{0.667\ 08\ \text{J}}{0.085\ \text{kg}}} = \sqrt{\frac{0.667\ 08\ \text{kg·m}^2/\text{s}^2}{0.085\ \text{kg}}} = \sqrt{7.848\ \text{m}^2/\text{s}^2} = 2.801\ 428\ 207\ \text{m/s}$

The speed of the egg just before impact is 2.8 m/s.

continued on next page

d. This question asks for magnitude and direction, so a vector approach is used. Let the direction of the bag and its contents (forward) prior to impact be considered the positive direction.

$m = 0.085 \text{ kg}$

$\vec{v} = 2.801\,428\,207 \text{ [forward]}$
$= +2.801\,428\,207 \text{ m/s}$

$\vec{p} = ?$

$$\begin{aligned}\vec{p} &= m\vec{v} \\ &= (0.085 \text{ kg})(+2.801\,428\,207 \text{ m/s}) \\ &= +0.238\,121\,397\,6 \text{ kg·m/s} \\ &= +0.24 \text{ kg·m/s}\end{aligned}$$

The momentum of the egg just before impact is 0.24 kg·m/s[forward].

e. $\vec{p}_f = 0 \quad \leftarrow \vec{v}_f = 0$

$\vec{p}_i = 0.238\,121\,397\,6 \text{ kg·m/s [forward]}$
$= +0.238\,121\,397\,6 \text{ kg·m/s}$

$\Delta\vec{p} = ?$

$$\begin{aligned}\Delta\vec{p} &= \vec{p}_f - \vec{p}_i \\ &= -\vec{p}_i \\ &= -(+0.238\,121\,397\,6 \text{ kg·m/s}) \\ &= -0.24 \text{ kg·m/s}\end{aligned}$$

The change in momentum is 0.24 kg·m/s[backward].

f. $\Delta\vec{p} = -0.238\,121\,397\,6 \text{ kg·m/s}$

impulse $= ?$

$$\begin{aligned}\text{impulse} &= \vec{F}\Delta t \\ &= \Delta\vec{p} \\ &= -0.238\,121\,397\,6 \text{ kg·m/s} \\ &= -0.24 \text{ kg·m/s}\end{aligned}$$

The impulse required to stop the bag is 0.24 kg·m/s[backward].

g. $\Delta\vec{p} = -0.238\,121\,397\,6 \text{ kg·m/s}$

$\Delta t = 0.040 \text{ s}$

$\vec{F} = ?$

$$\begin{aligned}\vec{F}\Delta t &= \Delta\vec{p} \\ \vec{F} &= \frac{\Delta\vec{p}}{\Delta t} \\ &= \frac{-0.238\,121\,397\,6 \text{ kg·m/s}}{0.040 \text{ s}} \\ &= -6.0 \text{ N}\end{aligned}$$

A force of 6.0 N[backward] acted on the bag and its contents during the collision.

h. $\vec{v}_i = +2.801\,428\,207 \text{ m/s}$

$\vec{v}_f = 0$

$\Delta t = 0.040 \text{ s}$

$\vec{a} = ?$

$$\begin{aligned}\vec{a} &= \frac{\vec{v}_f - \vec{v}_i}{\Delta t} \\ &= \frac{-\vec{v}_i}{\Delta t} \quad \leftarrow \vec{v}_f = 0 \\ &= \frac{-(+2.801\,428\,207 \text{ m/s})}{0.040 \text{ s}} \\ &= -70.035\,705\,18 \text{ m/s}^2 \\ &= -70 \text{ m/s}^2\end{aligned}$$

The acceleration of the egg is 70 m/s^2 [backward].

i. $m = 0.085 \text{ kg}$

$\vec{a} = -70.035\,705\,18 \text{ m/s}^2$

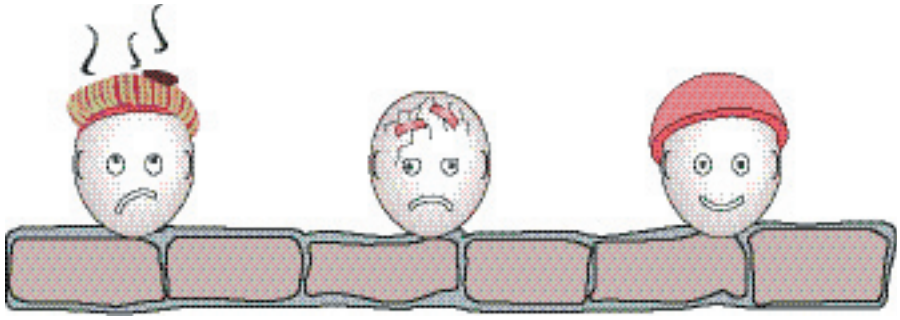
$\vec{F}_{net} = ?$

$$\begin{aligned}\vec{F}_{net} &= m\vec{a} \\ &= (0.085 \text{ kg})(-70.035\,705\,18 \text{ m/s}^2) \\ &= -6.0 \text{ N}\end{aligned}$$

A force of 6.0 N[backward] acted on the bag and its contents.

Practice

23. Answer questions a. to i. of Example Problem 2.13 for a bag and contents with a mass of 0.092 kg that is released from a height of 0.65 m.
24. Answer questions a. to i. of Example Problem 2.13 for a bag and contents with a mass of 0.088 kg that is released from a height of 1.00 m.



Investigation

Designing and Testing a Helmet

Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting
- ✓ Communication and Teamwork

Purpose

You and your partners will design and test a helmet to protect an egg test dummy from a frontal collision. Specifically, the helmet must meet the following criteria:

- must protect against a frontal collision with a rigid barrier
- must not cover eyes and ears
- must continue to provide protection after a number of severe frontal impacts
- must fit into a medium-sized, resealable, plastic bag (approximately 17.8 cm x 20.3 cm) including the egg test dummy

Materials

- 2 raw eggs (large size)
- 2 resealable, plastic bags
- 3-cm paper clamp
- wide elastic band
- empty, single-serving yogurt container (125 mL or 175 mL)
- 10 cm ¥ 10 cm ¥ 5 cm block of medium-density foam (This is the type of foam used to make cushions.)
- scissors
- knife with serrated edge (e.g., steak knife)
- 2 metre-sticks
- analytical balance
- twine
- cement block

CAUTION!

Use caution cutting the materials to make the helmet. The foam is best cut with a serrated knife and then trimmed with a pair of scissors. The yogurt container can be cut with a pair of scissors once a small hole has been made with the serrated knife. The use of a utility knife is not recommended—it is ineffective with the foam and is very dangerous.

Procedure

step 1: Set up a test swing apparatus similar to the one in Figure B2.20 on page 279. The twine for this apparatus should ideally be attached to the ceiling to allow for a large range of height values and an unobstructed path to the cement block.

step 2: Meet with your group, and begin discussing the design of your helmet. The main components suggested in the materials for the helmet are a yogurt container (a hard shell), a piece of foam (an energy-absorbing liner), and a wide elastic band (a chin strap). If you wish to use other materials, ask your teacher for approval. Remember, your helmeted egg test dummy must be able to fit inside the freezer bag.

step 3: Once you have agreed on a design for the helmet, divide the tasks among the group members. Tasks include shaping the materials; preparing the data table; and drawing the eyes, ears, and other features on your two egg test dummies. Follow the template in Figure B2.19.

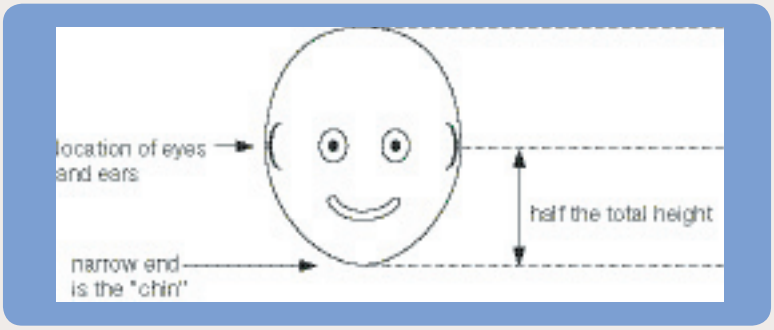


Figure B2.19: Be creative when it comes to drawing the features of your egg test dummy.

step 4: Copy the following table into your notebook or into a spreadsheet.

Trial	Egg Without Helmet	Egg with Helmet
Mass of Egg, Helmet, and Clamp (kg)		
Height Above Reference Level (m)		
Gravitational Potential Energy at Release Point (J)		
Kinetic Energy Just Before Impact (J)		
Speed Just Before Impact (m/s)		
Momentum Just Before Impact (kg□m/s)		
Approximate Change in Momentum Due to Impact (kg□m/s)		
Approximate Impulse Delivered During Impact (kg□m/s)		
Estimated Time of Impact (s)	0.010	0.040
Approximate Acceleration During Impact (m/s^2)		
Approximate Force Exerted During Impact (N)		

step 5: Once the helmet is complete, bring it and your egg test dummies to the test swing.

step 6: The first trial involves the egg test dummy with no helmet. Place the egg test dummy in a plastic bag. Determine the mass of the egg test dummy, the bag, and the paper clamp. Record this value in the table.

step 7: Use the clamp to attach the plastic bag to the test swing. Carefully remove as much air as possible from the bag before sliding your fingers along the seal to lock it shut. Ensure that the egg test dummy is facing the cement block. Adjust the position of the cement block so that the front of the egg test dummy is just grazing the front surface of the block when the swing is in the rest position.

step 8: Measure the distance from the middle of the egg to the surface supporting the cement block. This is the reference level. Pull the swing back until the height of the middle of the egg is 2.0 cm above the reference level. Refer to Figure B2.20.

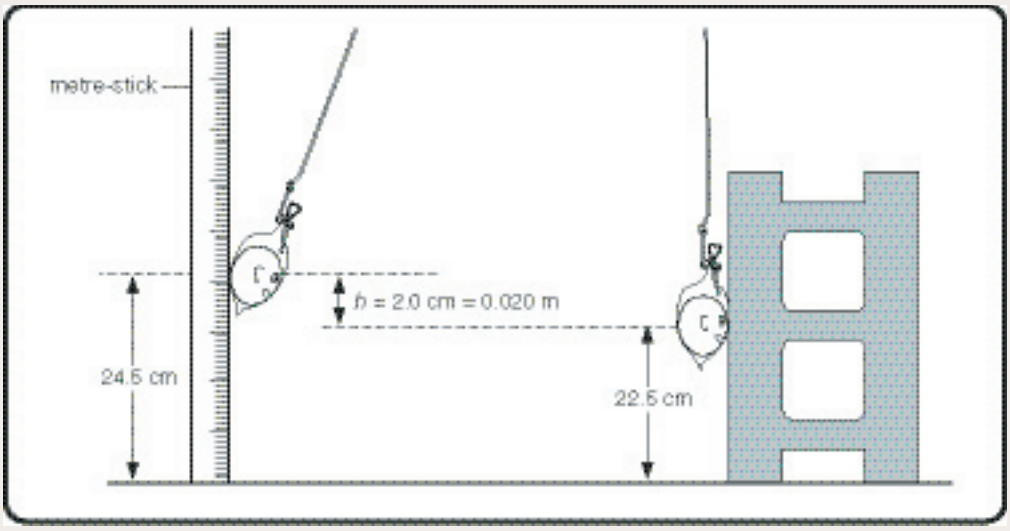


Figure B2.20: Make sure the face of the egg test dummy is facing the cement block.

step 9: Release the egg so it hits the cement block. Inspect the egg for damage. If there is no damage, repeat step 8 by increasing the height in 2.0-cm increments until the shell of the egg cracks. Record this height in the table.

step 10: Sketch a diagram to illustrate the pattern of cracking and other evidence of damage to the egg.

step 11: Repeat steps 7 to 10 for the helmeted egg test dummy. The only modification necessary is that the height above the reference level can be increased in 50-cm increments. Once again, as soon as this egg shows signs of damage, sketch the pattern of cracking and other evidence of damage.

Analysis

1. Refer to your sketches of the patterns of cracking and other evidence of damage to both egg test dummies.
   a. Explain what could account for the damage to the egg with no helmet.
   b. Explain what could account for the damage to the egg with a helmet.
2. Complete the table by calculating the remaining values. If you run into difficulties, use the process outlined in Example Problem 2.13 as a guide.
3. Compare the speed of the egg required to cause damage for the trial with no helmet to the trial with a helmet. How many times faster was the helmeted egg able to go before experiencing damage?
4. Compare the force exerted on the egg required to cause damage for the trial with no helmet to the trial with a helmet. How many times larger was the force on the helmeted egg?
5. Consider the ratios you developed in questions 3 and 4.
   a. Use the concept of impulse to account for the smaller ratio for the force values.
   b. Use the design of your helmet to account for the smaller ratio for the force values.
6. Refer to the kinetic energy value prior to impact in each case.
   a. Use the concept of work to account for the difference in kinetic energy.
   b. Use the design of the helmet to account for the differences in kinetic energy and work done.

Evaluation

7. Compare your sketches describing the evidence of damage with those of other groups. Account for similarities and differences between your results and the results of other groups.
8. Compare your values for force and impulse with those of other groups. Account for similarities and differences between your results and the results of other groups.
9. If you were to build another helmet for an egg test dummy, what would you do differently?

Protecting Your Head

Now that you have finished designing a helmet for an egg test dummy, it is appropriate to think about the protection you provide for your head during different activities. Which activities do you participate in that require a helmet? Some possibilities include riding all-terrain vehicles (ATVs), playing hockey, downhill skiing, snowboarding, and inline skating. The activity most likely on everyone's list is cycling. Since most people learn to ride a bicycle at a young age and can continue to ride a bike into adulthood, the use of bicycle helmets has received more public attention across Canada, including legislation for mandatory use.

Many people have strong opinions regarding the mandatory use of bicycle helmets. At the heart of the issue is this question: "What evidence is available to support the idea that the use of bicycle helmets results in a significant reduction in head injuries among cyclists?" You will have an opportunity to answer this question in the next activity.

Utilizing Technology

Collecting Evidence—Bicycle Helmets and Injury Reduction

Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting
- ✓ Communication and Teamwork

Question

What evidence is available to support the idea that the use of bicycle helmets results in a significant reduction in head injuries among cyclists?

Researching the Issue

Use the Internet to collect information related to the question and to alternative perspectives on this issue.

Analysis

1. Describe the overall trends in the data you collected.

Evaluation

2. Share your findings with others. How do their findings differ from yours? Are the arguments made to support these views consistent with the information you researched? Did other students find additional information unknown to you? How has your opinion of bicycle helmets changed since you started?

2.6 *Summary*

The designing and testing of helmets uses many of the key concepts from this unit: speed, force, momentum, impulse, acceleration, and Newton's laws of motion. Ideas from previous courses—such as work, potential energy, and kinetic energy—also play a key role in the data analysis during the testing process.

Even though there is a wealth of technical information that supports the use of helmets in activities like cycling, some people still choose not to use them. Legislation that makes the use of helmets mandatory for all cyclists remains controversial.

2.6 Questions

Knowledge

1. Define the following terms.
   a. work
   b. kinetic energy
   c. gravitational potential energy

Applying Concepts

2. During a collision, a force of 9.0×10^6 N displaces a car bumper 0.080 m. Determine the work done on the bumper by the force of the collision.

3. A 3000-kg truck is travelling 22 m/s. Calculate the kinetic energy of the truck.

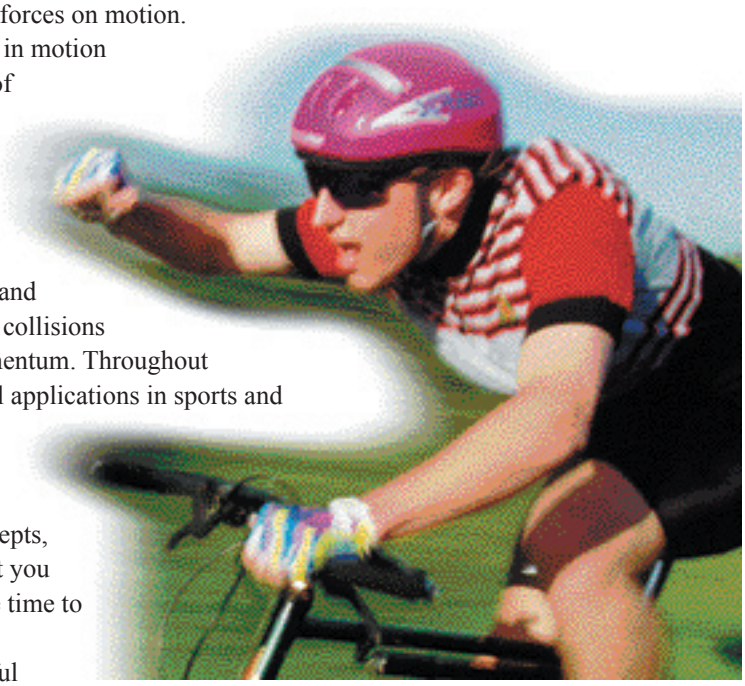
4. A 2500-kg car is hoisted 1.80 m vertically by a hydraulic jack. Determine the gravitational potential energy of the car at this position.

5. If 40.0 J of work is done lifting an object, how much gravitational potential energy will the object gain?

6. Explain how a bicycle helmet could save your life if you fell off your bicycle and hit your head on the curb.

Chapter 2 Summary

In this chapter you continued your study of the effect of forces on motion. You first studied how the mass and velocity of an object in motion combined to create a new property called "the quantity of motion," or momentum. You then studied how a change in motion requires a force over a time interval, called an impulse, and how this impulse causes a change in momentum. This impulse-change in momentum concept is the fundamental scientific concept affecting the design of safety devices for sports and transportation technologies. You analyzed three types of collisions and verified and applied the law of conservation of momentum. Throughout the chapter, these concepts were applied to technological applications in sports and transportation safety devices.



Summarize Your Learning

In this chapter you learned a number of new terms, concepts, equations, and techniques for problem solving. Now that you have come to the end of Chapter 2, this is an appropriate time to focus on the patterns within the things you have learned.

Since the pattern has to be in a form that is meaningful to you, there are some options as to how you can create this summary. Each of the following options is described on pages 552 and 553.

Option 1: Draw a concept map or a web diagram.	Option 2: Create a point-form summary.	Option 3: Write a story using key terms and concepts.	Option 4: Create a colourful poster.	Option 5: Build a model.	Option 6: Write a script for a skit (a mock news report).

Chapter 2 Review Questions

Knowledge

1. The following table summarizes the important quantities studied in this chapter. Copy and complete the table in your notebook.

Name	Symbol	Most Common Unit	Formula
momentum			
change in momentum			
impulse			
Newton's third law			
conservation of momentum			
work			
kinetic energy			
gravitational potential energy			

2. Identify two quantities that must be known to determine the momentum of an object.

3. Describe *momentum* in terms of motion.

4. Define *impulse* using words and equations.

5. During a collision, describe how a seat belt reduces injury to an occupant of a vehicle.

6. State Newton's third law, and give an example of how it is used.

7. While floating in a pool, you throw a polo ball straight up in the air. Describe what will happen to you as a consequence of throwing the ball upward. State the scientific law that explains your motion.

8. State the law of conservation of momentum using a sentence and using an equation.

9. List three types of collisions or interactions that can occur between two objects.

Applying Concepts

10. Prove that the units for impulse are the same as the units for change in momentum.

11. A skateboarder and a skateboard have a total mass of 66 kg and are initially gliding on a smooth concrete surface at a velocity of 2.6 m/s[E]. They crash into a vertical foam barrier, coming to a stop in 0.12 s. Assuming that the skateboarder and skateboard act as one combined mass throughout the interaction, calculate the following values.

- **a.** initial momentum
- **b.** final momentum
- **c.** change in momentum
- **d.** impulse provided by the foam barrier on the skateboarder and the skateboard
- **e.** force provided by the foam barrier on the combined mass
- **f.** acceleration of the combined mass
- **g.** initial kinetic energy of the combined mass
- **h.** final kinetic energy of the combined mass
- **i.** change in kinetic energy of the combined mass

12. Answer the following if the foam barrier in question 11 exerted a resisting force of 1.5×10^3 N to stop the skateboarder and the skateboard in 0.15 m.

- **a.** Calculate the work done by the foam barrier in stopping the combined mass.
- **b.** Describe the relationship between the work done by the foam barrier and the change in kinetic energy of the skateboarder and the skateboard.

13. A 900-kg compact car is travelling 60 km/h[N].

a. Calculate the initial momentum of the car.

b. The compact car crashes into the rear of a 1500-kg truck travelling 10 km/h[N]. After the collision, the compact car remains at rest. Calculate the final velocity of the truck.

c. Determine the change in momentum of the car.

d. If the time of impact during the collision was 0.15 s, calculate the force exerted by the truck in stopping the car.

e. The force of the truck on the car compressed the bumper of the car a displacement of 0.060 m. Calculate the work done by the truck on the car.

f. Describe the energy changes in the car during the entire interaction.

14. If the compact car in question 13 hits and sticks to the truck, calculate the final velocity of the combined masses.

15. A 500-g ball is thrown against a wall with a velocity of 6.00 m/s. If the ball rebounds with a velocity of 5.00 m/s, calculate the

a. change in momentum of the ball

b. force provided by the wall on the ball if the time of impact was 0.22 s

16. Will a primary collision cause injury to a passenger? Explain your answer.

17. A 4.0-kg ball travelling 4.0 m/s[N] strikes another 2.0-kg ball travelling 1.0 m/s[N]. The two balls stick together after the collision and travel 3.0 m/s[N].

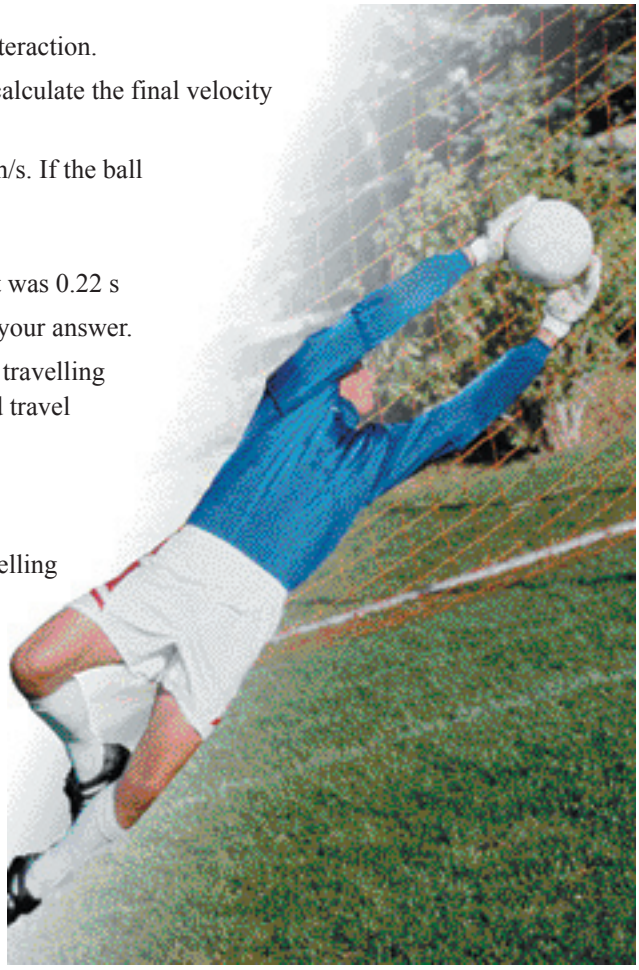
a. Show that momentum is conserved.

b. Show that kinetic energy is not conserved.

18. A 50-kg goalkeeper at rest catches a 0.700-kg soccer ball travelling directly towards him at 12.0 m/s.

a. Describe why it is less painful to catch the ball by letting your arms "give" while catching the ball rather than catching the ball with "rigid" arms.

b. If the goalkeeper lets his arms "give," the ball comes to rest in 1.2 s. If his arms are rigid, the ball comes to rest in 0.40 s. Calculate the force exerted by his arm on the ball in both cases.



19. A 1500-kg car travelling 90 km/h[N] collides with a 1200-kg minivan travelling 40 km/h[S]. After the collision, the two vehicles stick together.

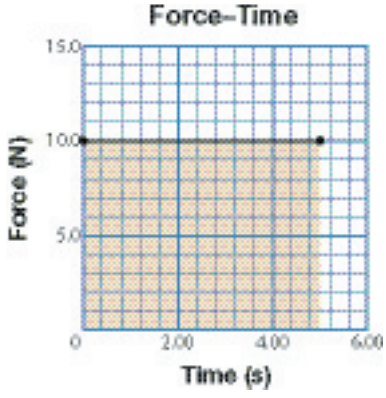
a. Calculate the initial momentum of the car and the minivan.

b. Using the law of conservation of momentum, determine the total momentum of the two vehicles after the collision.

c. Calculate the final velocity of the two vehicles after the collision in metres per second.

20. A constant force is applied to a 15.0-kg mass, initially at rest, over a specified time (as depicted in the force–time graph).

a. Determine the area under the line of the graph.

b. Identify the quantity determined by the area under the line.

c. Calculate the final speed of the mass at 5.00 s.